EROSION OF COHESIVE SEDIMENTS IN UNIFORM FLOW

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Abstract. The erosion of cohesive sediments under conditions of uniform flow has been studied. The rate of erosion and the total mass eroded increased linearly as bed shear stress increased. These results, along with additional experiments with varying water chemistry of the water column, will enable the erosion and transport of cohesive sediments to be more accurately predicted.

INTRODUCTION

The erosion and transport of sediments and associated contaminants is an area of great environmental concern. Cohesive sediments are composed mainly of clay particles which originate from the natural weathering of rocks. Because of the high specific surface area and reactivity of clay particles, contaminants like heavy metals and pesticides adsorb to clay particles in fine, cohesive sediments where they tend to accumulate without degradation (Singh and Subramanian, 1984; Sigg *et al.*, 1987).

Cohesive sediments may experience repeated cycles of deposition and resuspension depending on the composition of the sediments and variations in the water chemistry and hydrodynamic conditions of the water body in which they are found. These sediments may eventually be transported into estuarine environments where they are then deposited due to the abrupt changes in water chemistry that occur when a freshwater stream empties into saline water. The National Research Council (1993) concluded that "metals from past uncontrolled discharges still contaminate sediments, especially near harbors, and can be a significant source of contamination to overlying waters and local aquatic life".

In order to assess the water-quality impacts of sediment discharges, a critical research need is to be able to predict the rate at which fine cohesive sediments are resuspended into the water column under specific hydrodynamic conditions. It is well known that the resuspension of cohesive sediment is dependent on bed shear stress, τ_o, in excess of a critical value, τ_c, but the empirical constants used in sediment transport models to predict resuspension vary with type of clay, water content, total salt concentration, ionic species in the water, pH, and temperature (Mehta *et al.*, 1989). This research seeks to provide a more fundamental basis for determining the factors which control resuspension of cohesive sediments.

OBJECTIVES

On-going research is attempting to link the behavior of clay particles on a microscopic level to the hydrodynamic conditions which cause erosion on a macroscopic level. Specific objectives of the research are to investigate the effects of pH and natural organic matter on the erosion and transport of cohesive sediments and relate the results to microscopic, inter-particle forces including electrostatic, van der Waals, Born repulsion, and hydration forces.

METHODOLOGY

The erosion of kaolinite clay and a bottom sediment collected from the Calcasieu River near a contaminated industrial site in Lake Charles, Louisiana, is being studied. Experiments have been performed under conditions of uniform flow in a tilting flume which could be operated in either a once-through mode or a recirculating mode. The depth of flow ranged from 4.2 to 9.1 cm, and the mean velocities ranged between 0.33 and 0.54 m/s. The bed shear stress, τ_o, was varied from 1 to 2 N/m^2 by changing the pump discharge and bed slope.

A sample of the test sediment was resuspended in tap water and then allowed to settle for 24 hours into a sample tray. The sample tray was then placed into the flume bed. The remainder of the flume bed was filled with fine gravel having a mean size of 3.5 mm. Plan

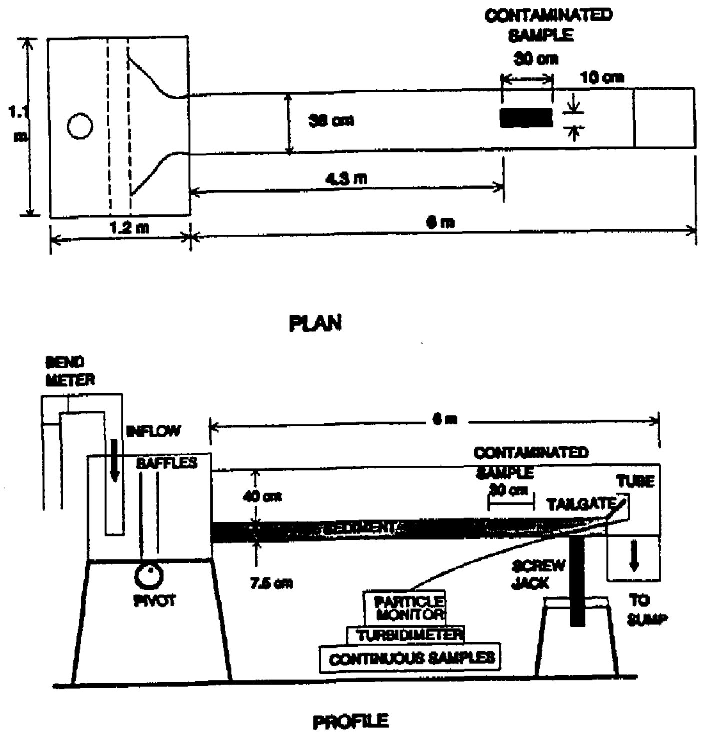

Figure 1. Plan and profile of recirculating flume.

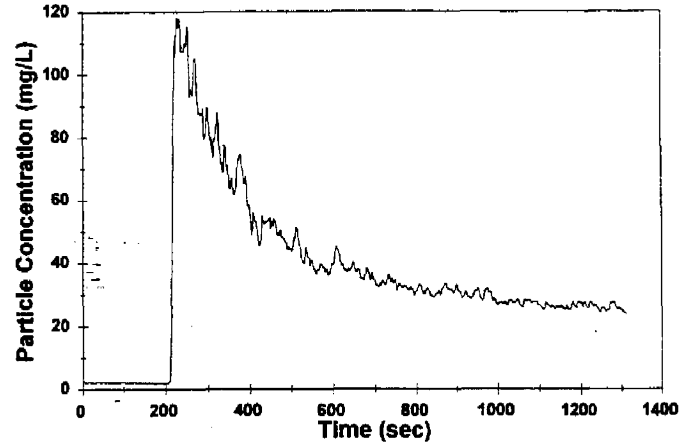

Figure 3. Typical concentration profile for erosion event.

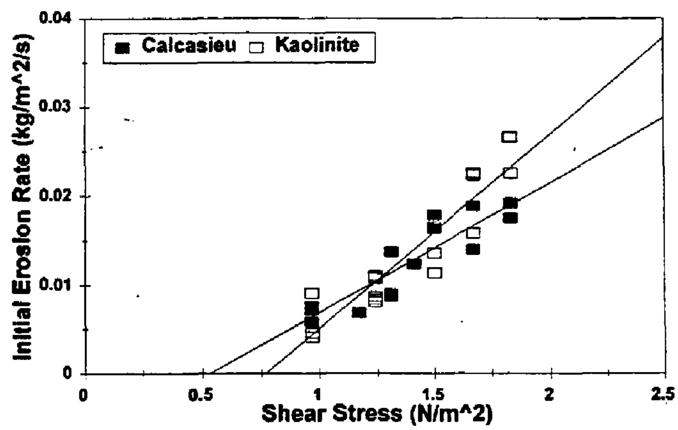

Figure 4. Initial erosion rates.

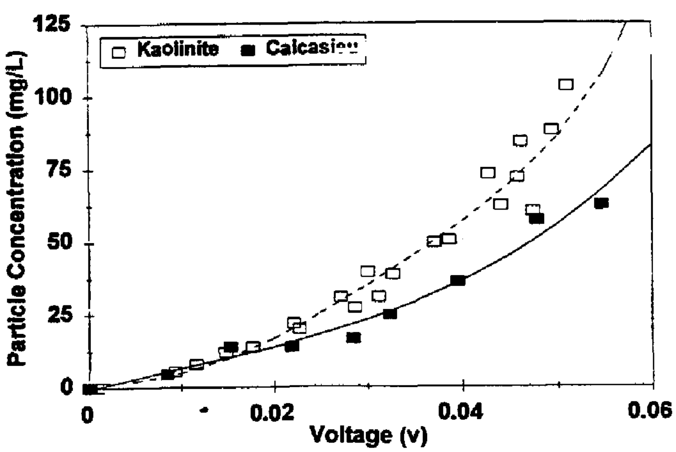

Figure 2. Particle monitor calibration curves.

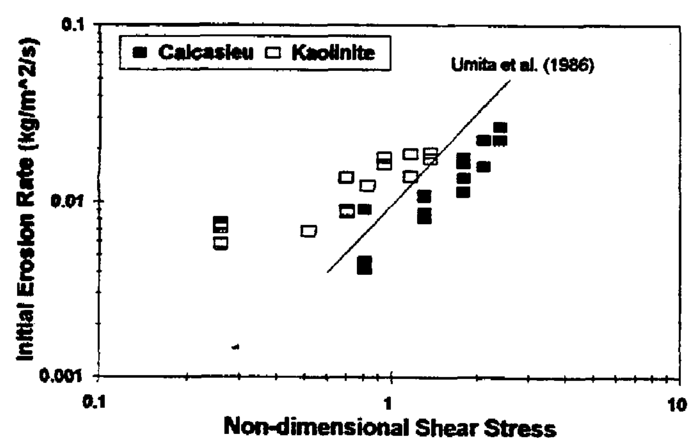

Figure 5. Variation of initial erosion rates with non-dimensional shear stress.

and profile views of the tilting flume are shown in Figure 1.

A Chemtrac particle monitor was used to monitor the concentration of eroding sediment in the plume which formed downstream from the sample tray. This instrument monitors the fluctuations in light intensity transmitted through a sample stream flowing in transparent flexible tubing. The variation in voltage output of the particle monitor has been calibrated with particle concentration for both of the sediments being studied. Calibration curves for the particle monitor are shown in Figure 2.

RESULTS

During each experiment, erosion occurred rapidly over the initial one minute and then gradually declined for approximately six to eight minutes, indicating that the sediment samples were partially consolidated. The concentration profile for a typical erosion event is shown in Figure 3. Both the rate of erosion and the total mass eroded increased linearly with increasing bed shear stress, τ_o, for the Calcasieu River sediment and kaolinite. Using the plot of the initial erosion rates versus shear stress in Figure 4, the value of the critical shear stress, τ_c, can be estimated by extrapolating to an erosion rate of zero (x-intercept). For the Calcasieu River sediment, τ_c was estimated as 0.54 N/m^2. For kaolinite, τ_c was estimated as 0.76 N/m^2. Even though kaolinite had a slightly higher critical shear stress than the Calcasieu River sediment, more kaolinite will erode at the upper range of shear stresses which were tested. In Figure 5, the initial erosion rates as a function of [(bed shear stress/critical shear stress) - 1], i.e., $[(\tau_o/\tau_c) - 1]$ are compared with data from the literature for an estuary sediment (Umita *et al.*, 1986).

Even though the characteristics of the two sediments were very different, the erosion rates were similar. The clay mineralogy of the two sediments was different. An X-ray diffraction analysis determined that the Calcasieu River sediment was a mixed-layer clay composed primarily of smectite (60-70%) and illite (30-40%). Also, the particle size distributions of the sediments were different. The kaolinite particles had a more uniform size of about 1.5 microns. The Calcasieu River sediment had a much broader size distribution, ranging from dispersed colloidal particles up to very fine sand.

The completed experiments were performed with the eroding fluid pH around 7. Additional experiments will focus on the effects of clay mineralogy and changing water chemistry on erosion. The effects of lower and higher pH conditions, increasing ionic strength, and the addition of natural organic matter is currently being investigated. Natural organic matter can also significantly affect the physical behavior of colloidal particles in water by causing either dispersion or flocculation. In general, organic matter will increase the dispersion of clay particles due to a combination of electrostatic stabilization and steric stabilization. However, in the presence of adequate concentrations of polyvalent metal ions, flocculation can occur.

CONCLUSIONS

For the two sediments which were studied, the initial erosion rates were similar and increased linearly with increasing shear stress. The estimated critical shear stress of the Calcasieu River sediment is slightly lower than critical shear stress of the kaolinite. With additional experiments, this research will enable a more accurate expression describing the erosion or resuspension of cohesive bottom sediments to be developed. This expression is expected to relate the process of erosion to the microscopic, inter-particle forces which control the behavior of cohesive sediments.

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